

Strong-Strong/Strong-Weak Beam-Beam Modeling: A Parallel Computational Tool and Applications

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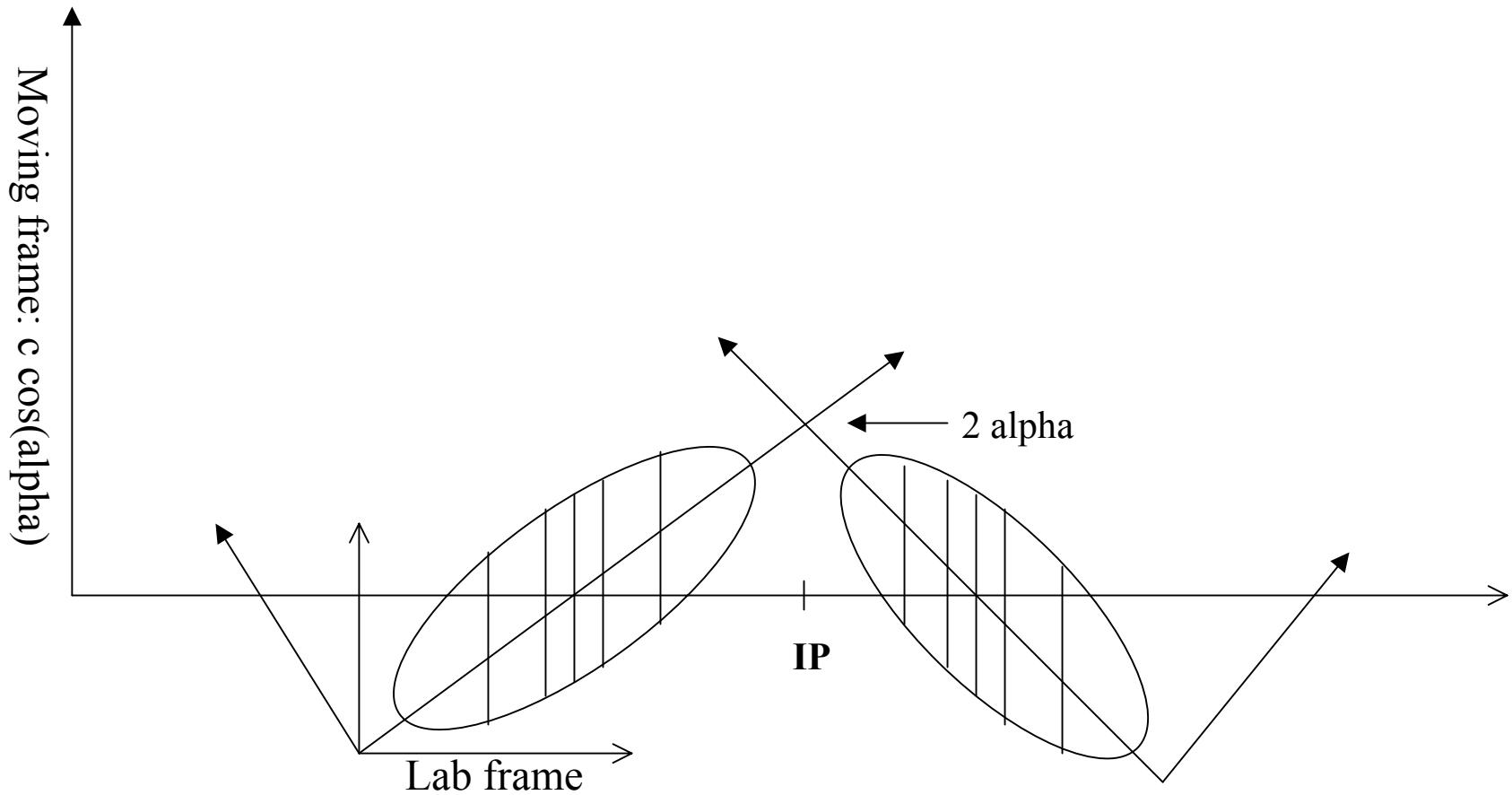
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BeamBeam3D:

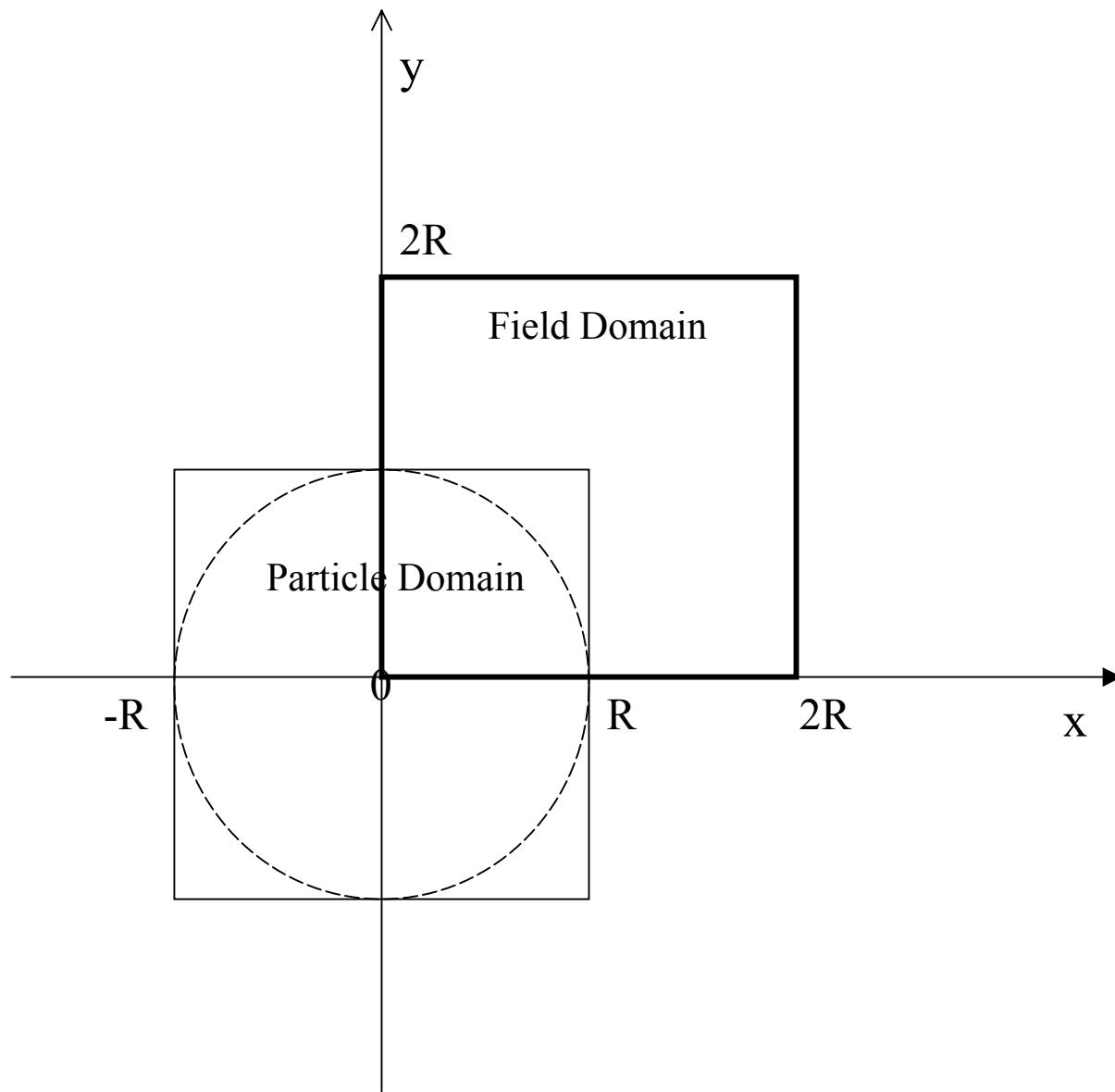
Parallel Strong-Strong / Strong-Weak Simulation Code

- Multiple physics models:
 - strong-strong (S-S); weak-strong (W-S)
- Multiple-slice model for finite bunch length effects
- New algorithm -- shifted Green function -- efficiently models long-range parasitic collisions
- Parallel particle-based decomposition to achieve perfect load balance
- Lorentz boost to handle crossing angle collisions
- W-S options: multi-IP collisions, varying phase adv,...
- Arbitrary closed-orbit separation (static or time-dep)
- Independent beam parameters for the 2 beams

Two Beam Collision with Crossing Angle Alpha

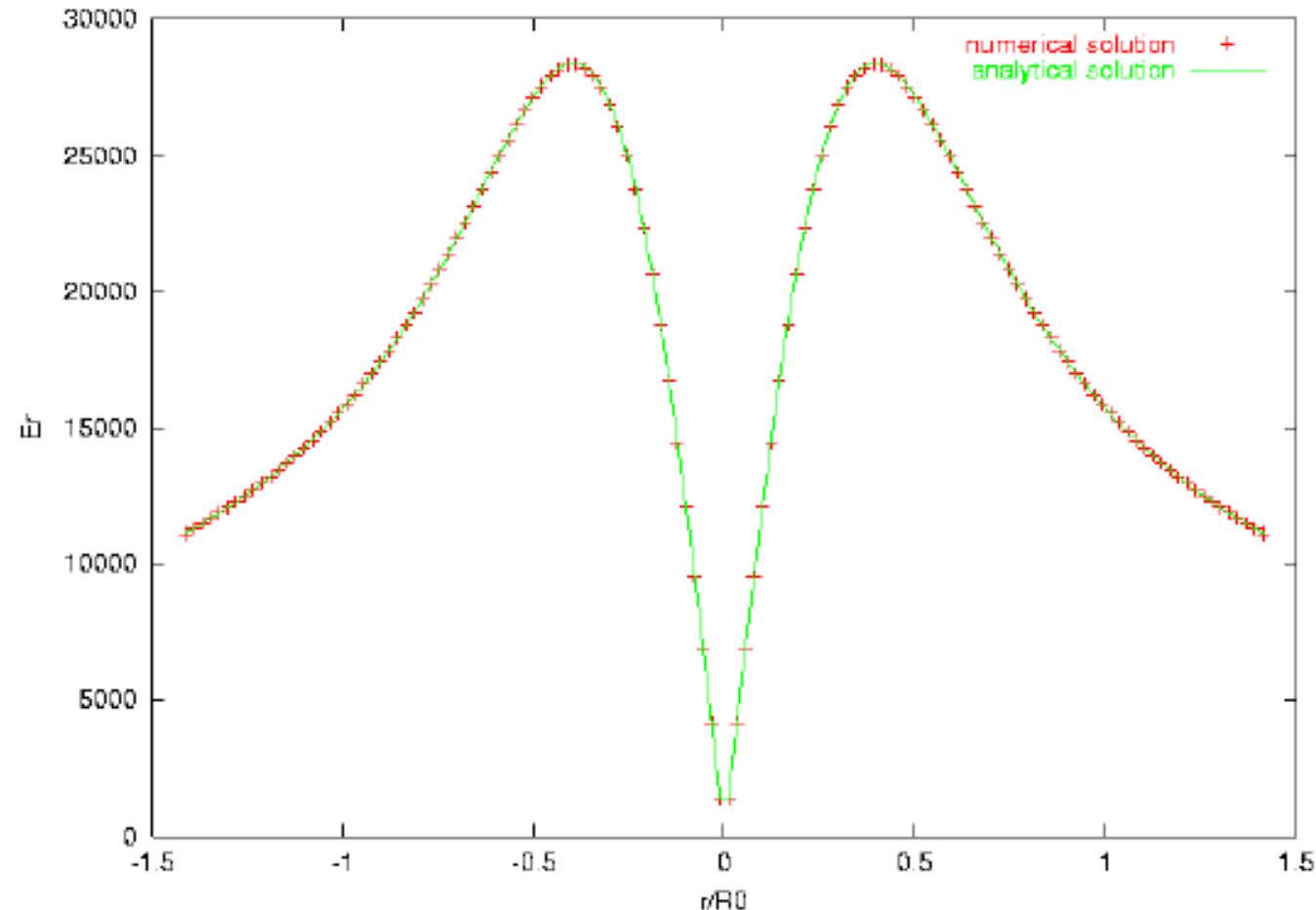


A Schematic Plot of the Particle Domain and the Field Domain



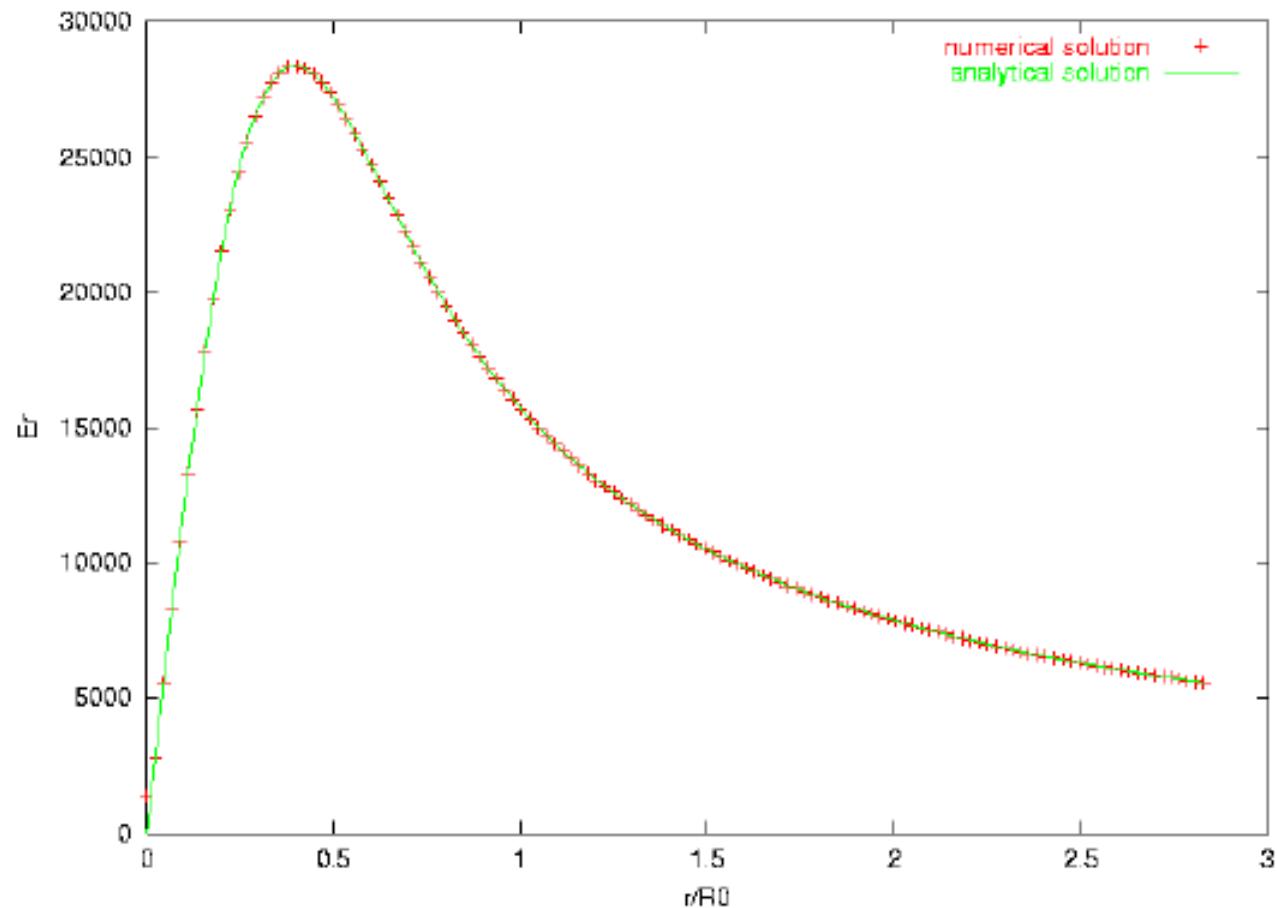
Comparison between Numerical Solution and Analytical Solution

Radial Electric Field vs. Distance inside the Particle Domain with Gaussian Density Distribution



Comparison between Numerical Solution and Analytical Solution

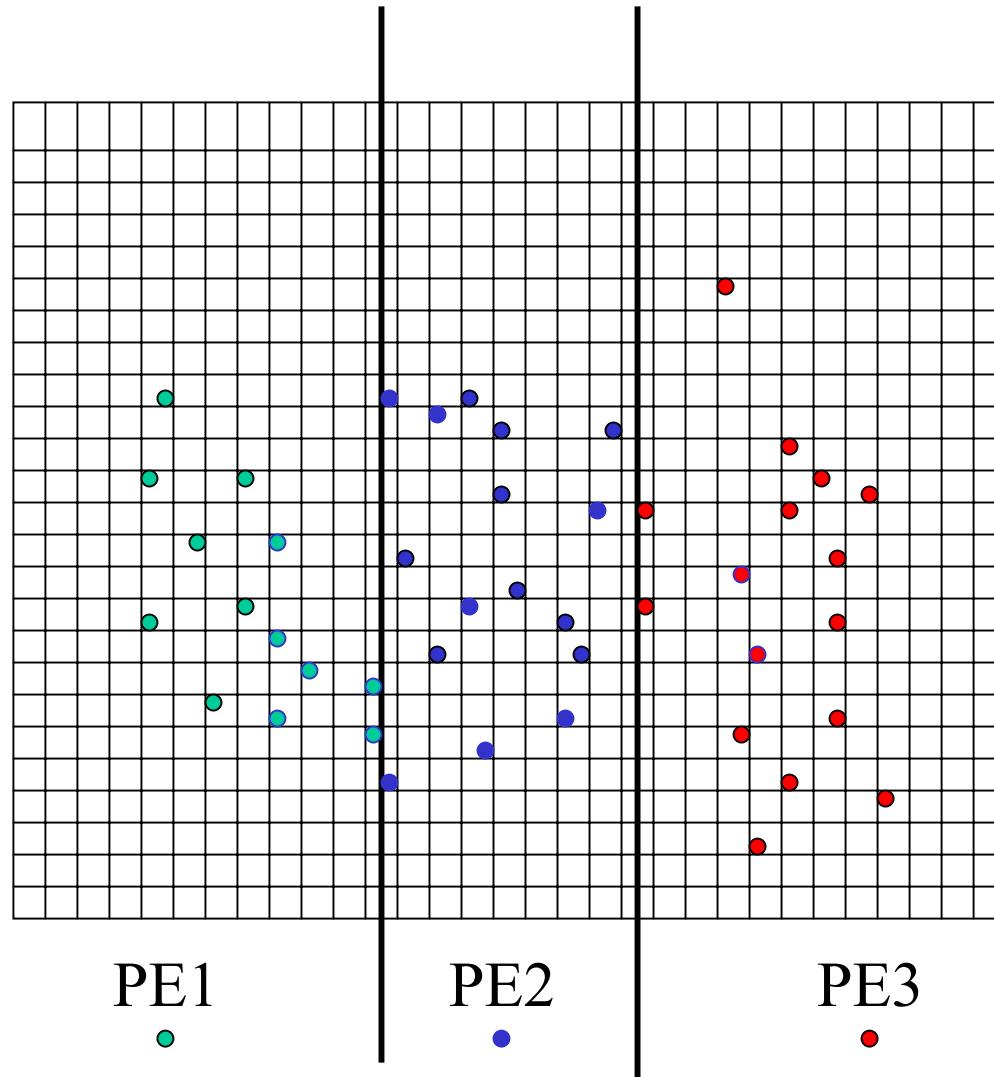
Radial Electric Field vs. Distance inside the Field Domain with Gaussian Density Distribution



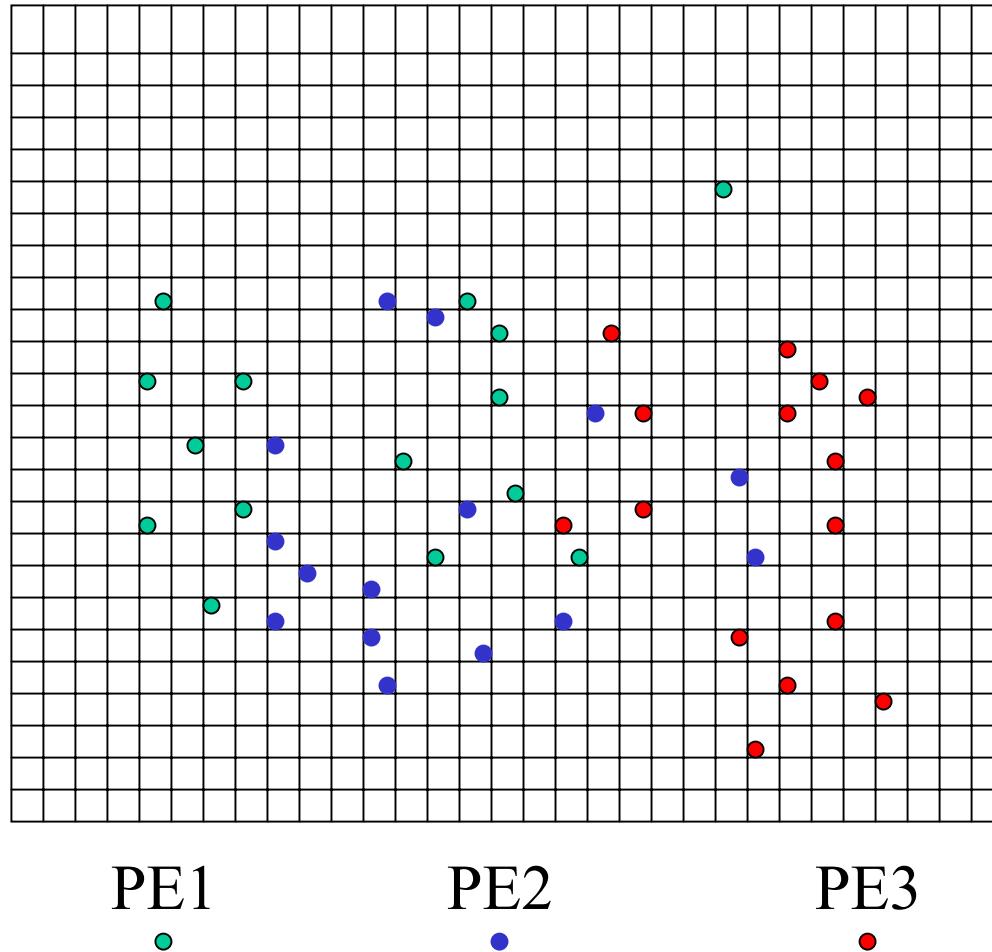
Parallel Implementation

- Uniformly distribute particles among processors
- Uniformly distribute the field domain among processors
- Exchange the local charge density among processors
- Solve the Poisson equation in parallel
- Collect the potential from the other processors

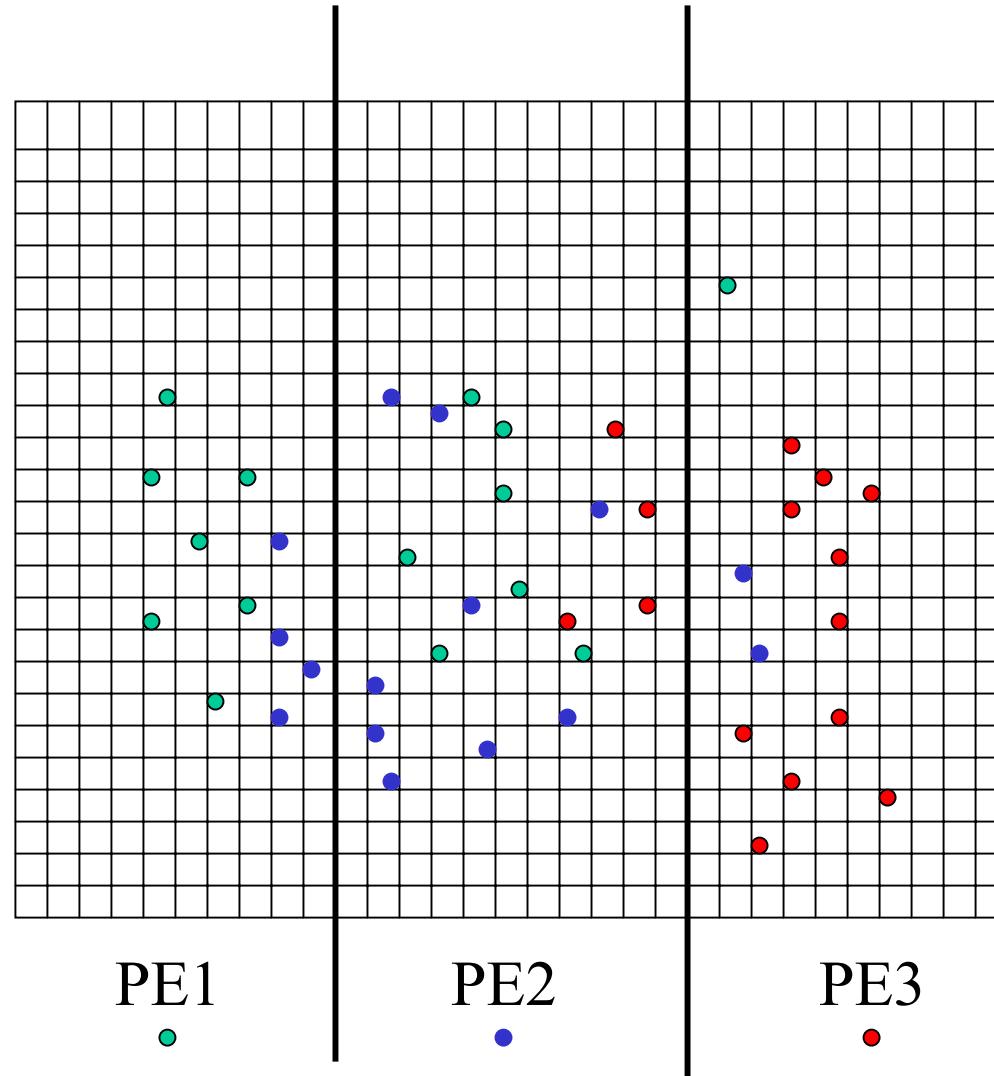
Domain Decomposition



Particle Decomposition

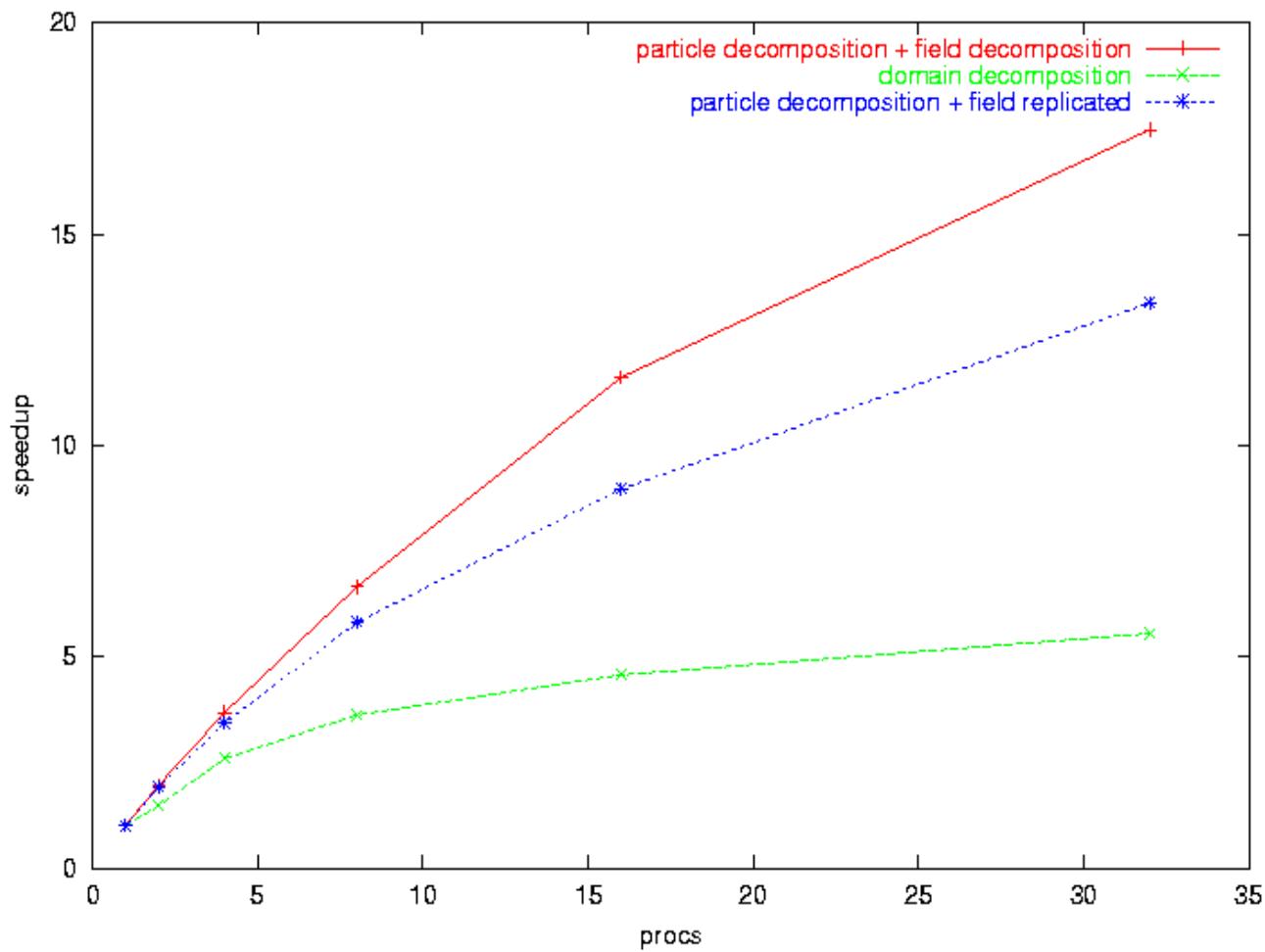


Particle and Field Decomposition



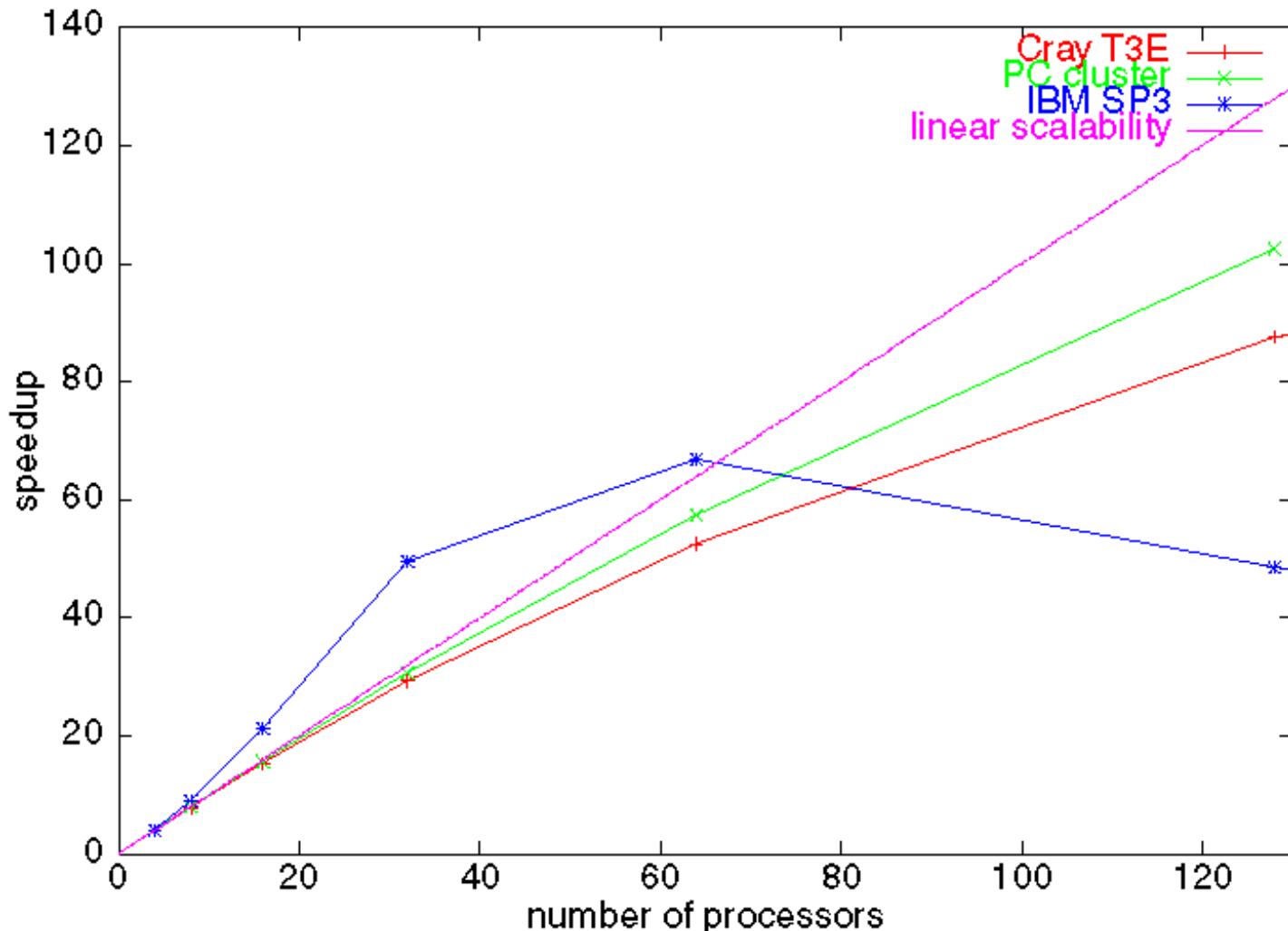
A Comparison of Scalability of Parallel Implementation Using

a) Domain-decomposition b) Particle-Decomposition c) Particle+Field-Decomposition



Scalability on Parallel Computers

(S-S: 5 slices, 2 million particles, 64 x 64)



Scalability on Parallel Computer (S-W: 1 million particles, 74 maps, 1000 turns)

PEs	time (sec)
128	1612
256	858
512	477
1024	303
2048	212

RHIC Physical Parameters for the Beam-Beam Simulations

Beam energy (GeV)	23.4
Protons per bunch	8.4e10
Beta (m)	3
Rms spot size (mm)	0.629
Betatron tunes	(0.22,0.23)
Rms bunch length (m)	3.6
Synchrotron tune	3.7e-4
Momentum spread	1.6e-3
Offset	1 sigma
Oscillation frequency	10 Hz

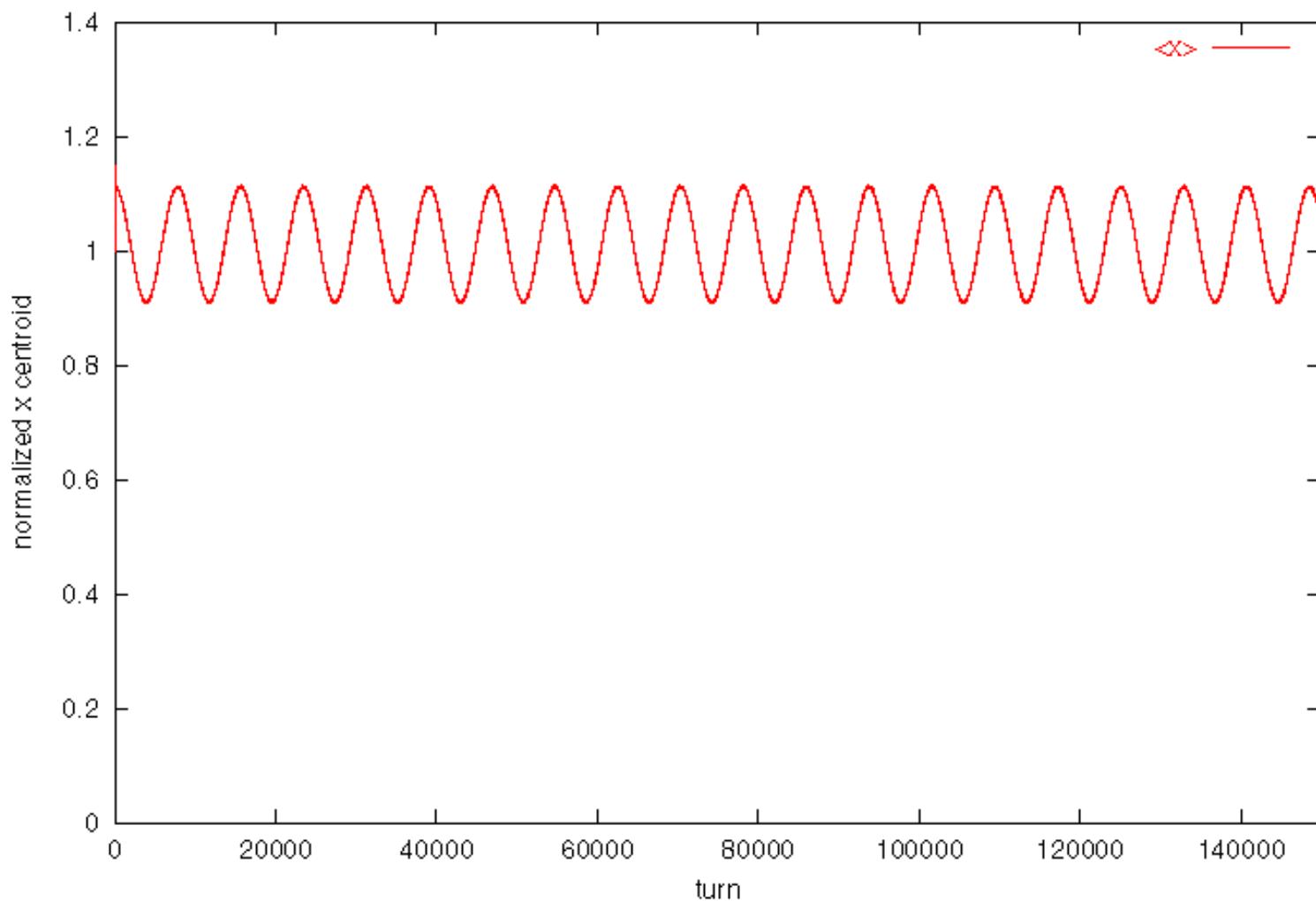
Emittance Growth in RHIC (beam 1)

	D ex/ex	D ey/ey	D (ex+ey)/(ex+ey)
Ref. no offset, 100K	0.307%	0.042%	0.175%
Static offset	0.308%	0.027%	0.167%
Dynamic offset	0.339%	0.047%	0.193%
Dynamic offset (2M)	0.332%	0.039%	0.185%
Dynamic offset (2)	0.337%	0.049%	0.193%
Ref. No offset, 300K	0.325%	0.0611%	0.193%
Static offset, 300K	0.341%	0.050%	0.196%
Dynamic offset, 300K	0.385%	0.079%	0.232%

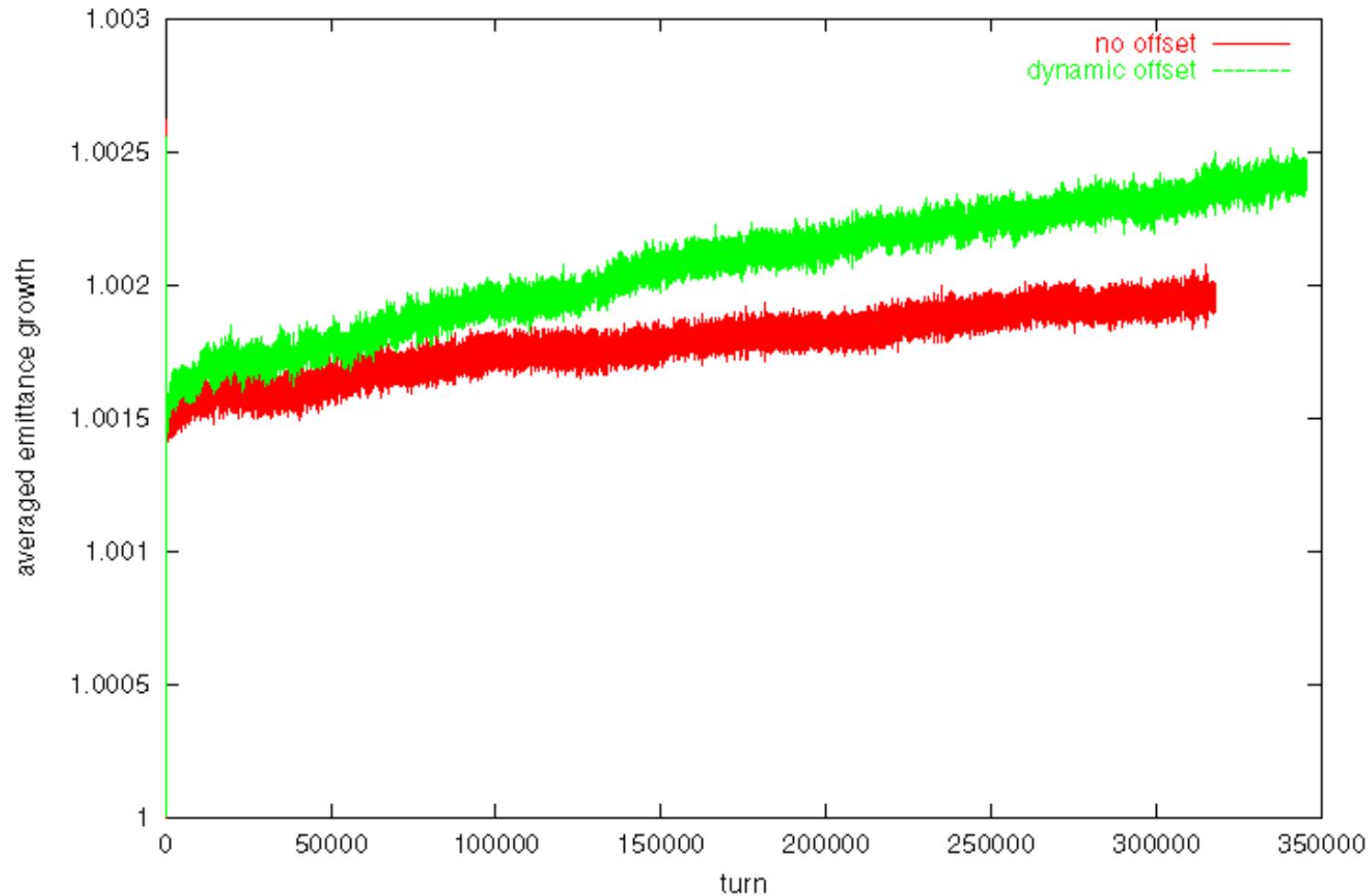
Emittance Growth in RHIC (beam 2)

	D ex/ex	D ey/ey	D (ex+ey)/(ex+ey)
Ref. no offset, 100K	0.270%	0.030%	0.150%
Static offset	0.306%	0.030%	0.168%
Dynamic offset	0.327%	0.048%	0.188%
Dynamic offset (2M)	0.324%	0.041%	0.182%
Dynamic offset (2)	0.330%	0.047%	0.189%
Ref. No offset, 300K	0.314%	0.071%	0.192%
Static offset, 300K	0.332%	0.051%	0.192%
Dynamic offset, 300K	0.385%	0.091%	0.238%

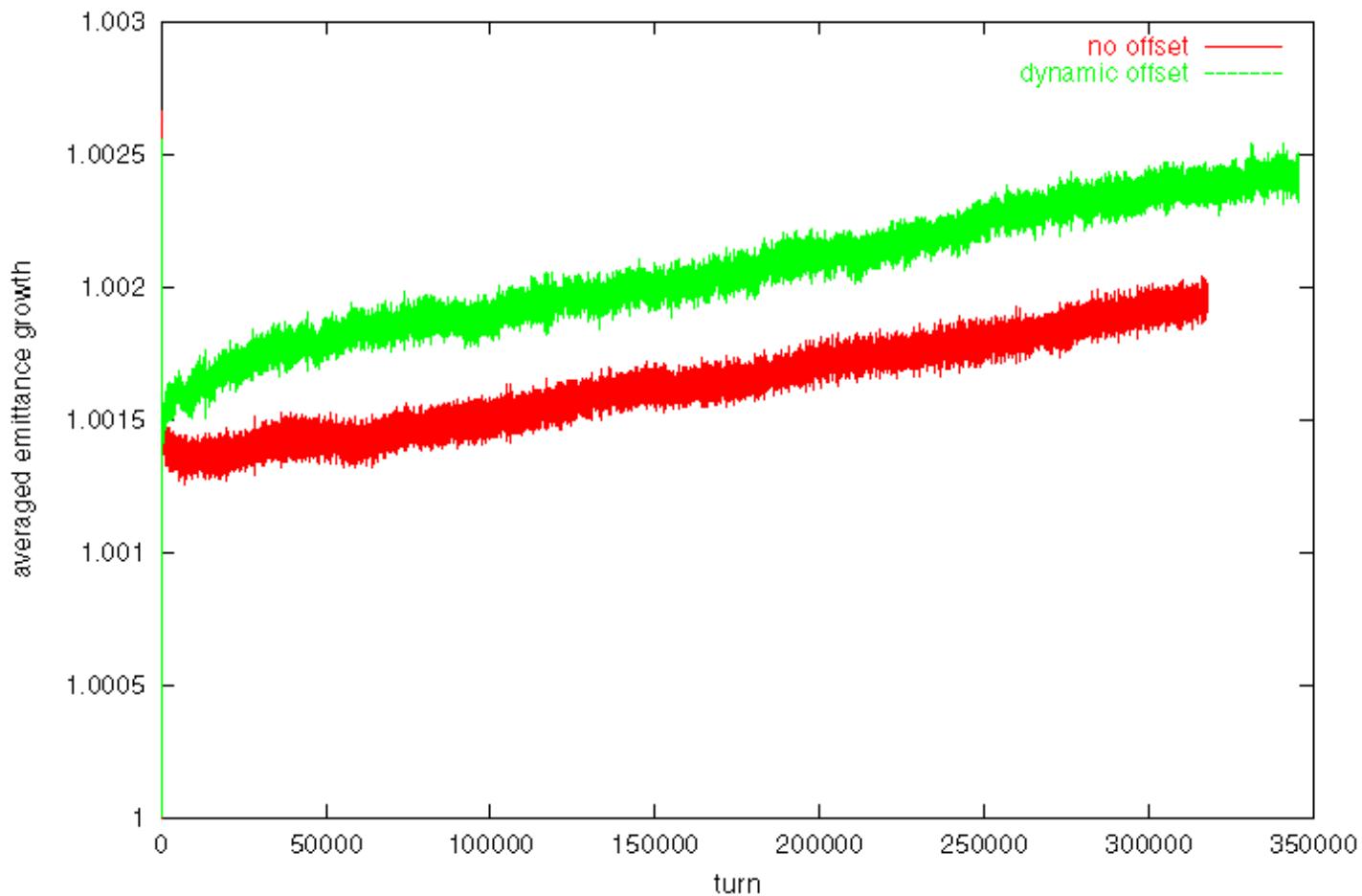
Horizontal Centroid Oscillation



Averaged Emittance Growth (Beam 1):



Averaged Emittance Growth (Beam 2)



Computation Model for Pbar Lifetime Calculation At 150 GeV in the Tevatron

- Strong-weak model with soft-Gaussian approximation of beam-beam interaction
- Seventy two collision points
- Seventy three linear transfer maps from MAD output
- One linear chromaticity kick per turn
- One stochastic random kick per turn
- Weighted particle sampling
- Least-square fitting for the pbar lifetime
- One million particles
- 100,000 turns

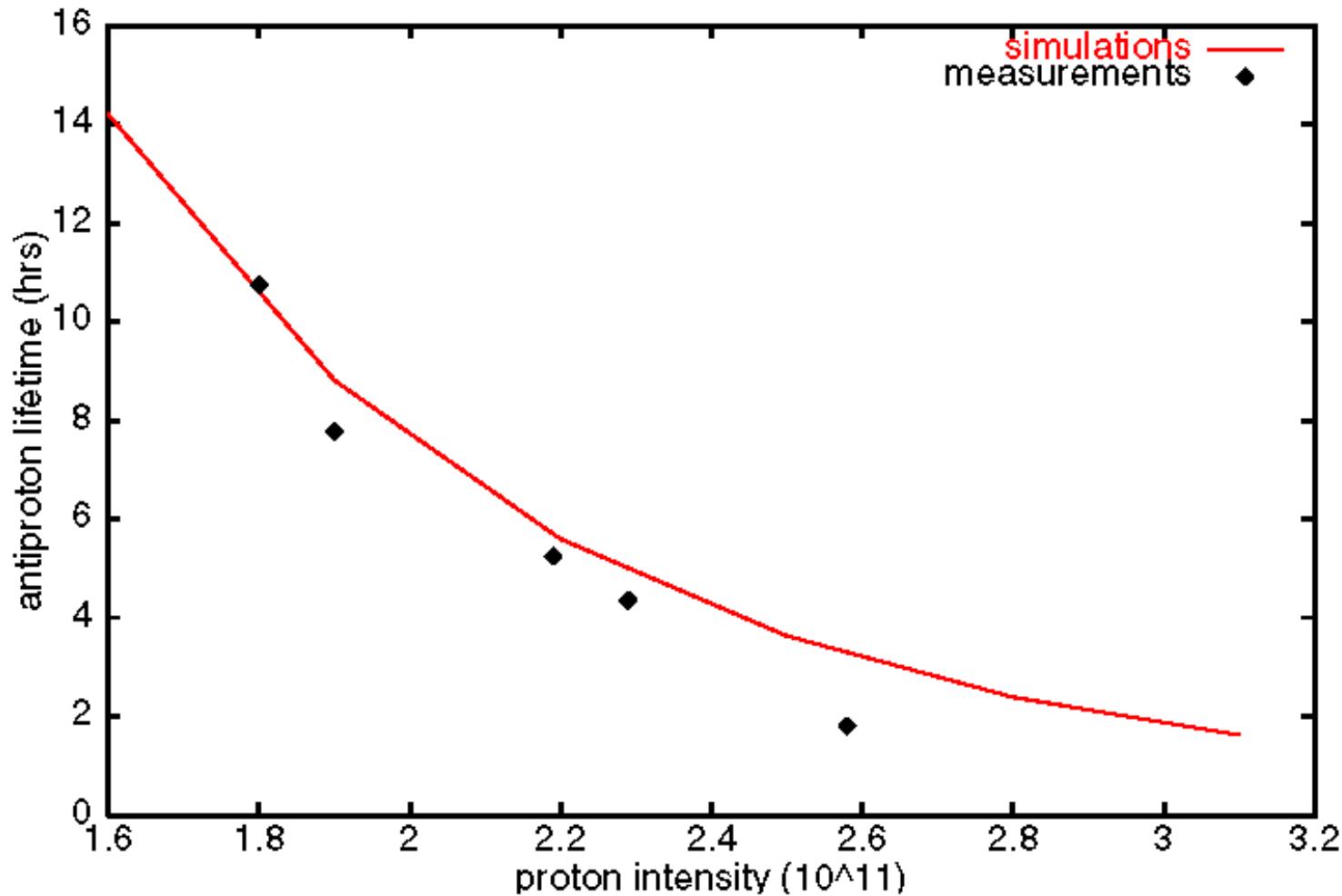
Parameter Study of Antiproton Lifetime

- Chromaticity
- Antiproton emittance
- Proton intensity
- Proton – antiproton separation

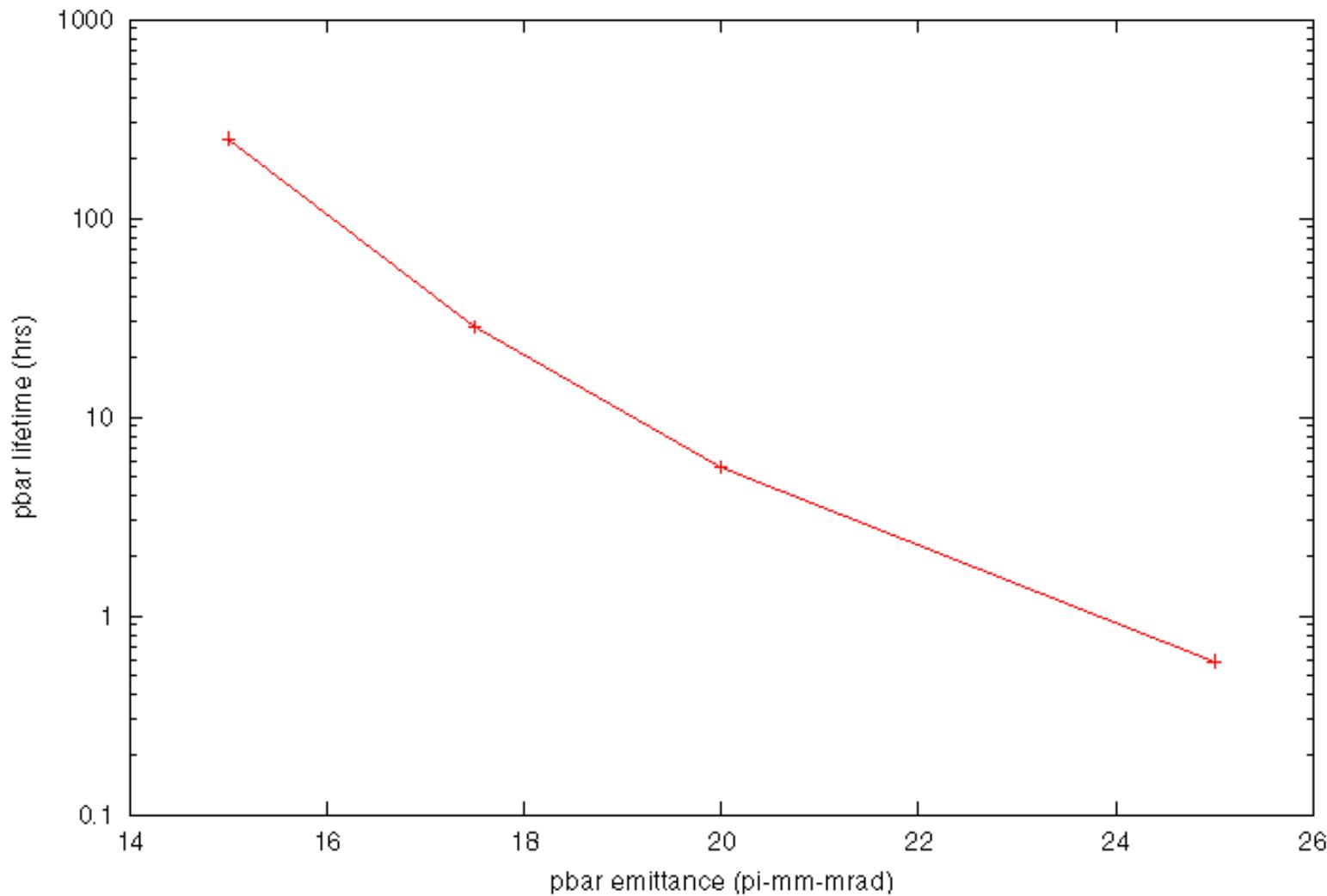
Reference Parameters

- Proton intensity: 2.2×10^{11} / per bunch
- Proton emittance: $25 \pi\text{-mm-mrad}$
- Proton momentum spread: 7×10^{-4}
- Proton rms bunch length: 0.9 m
- Antiproton emittance: $20 \pi\text{-mm-mrad}$
- Antiproton momentum spread: 4.31×10^{-4}
- Antiproton rms bunch length: 0.6 m
- Horizontal bare tune: 0.581
- Vertical bare tune: 0.576
- Horizontal chromaticity: 2
- Vertical chromaticity: 8
- Aperture size: 3.25 sigma

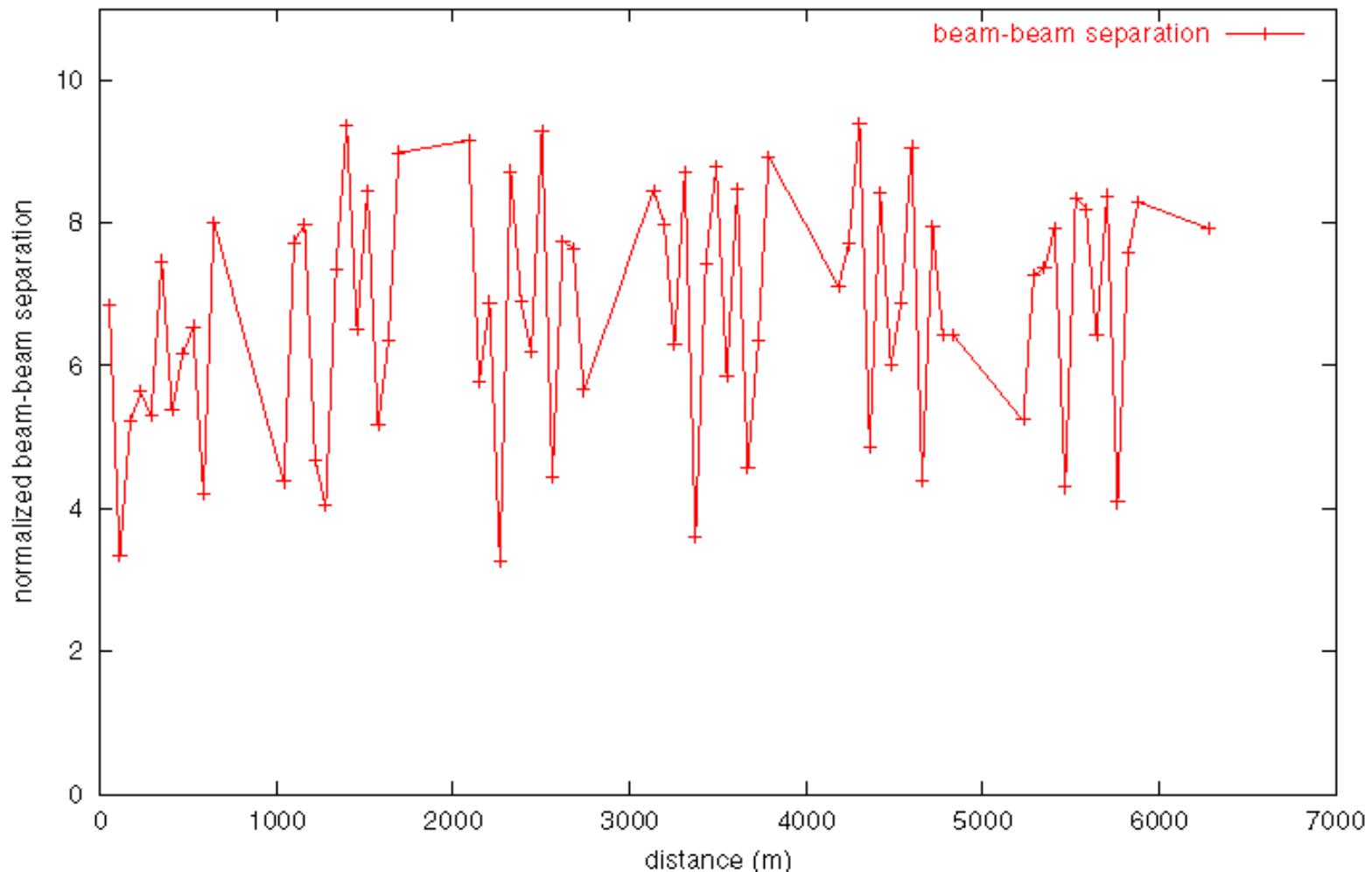
Antiproton Lifetime vs. Proton Intensity



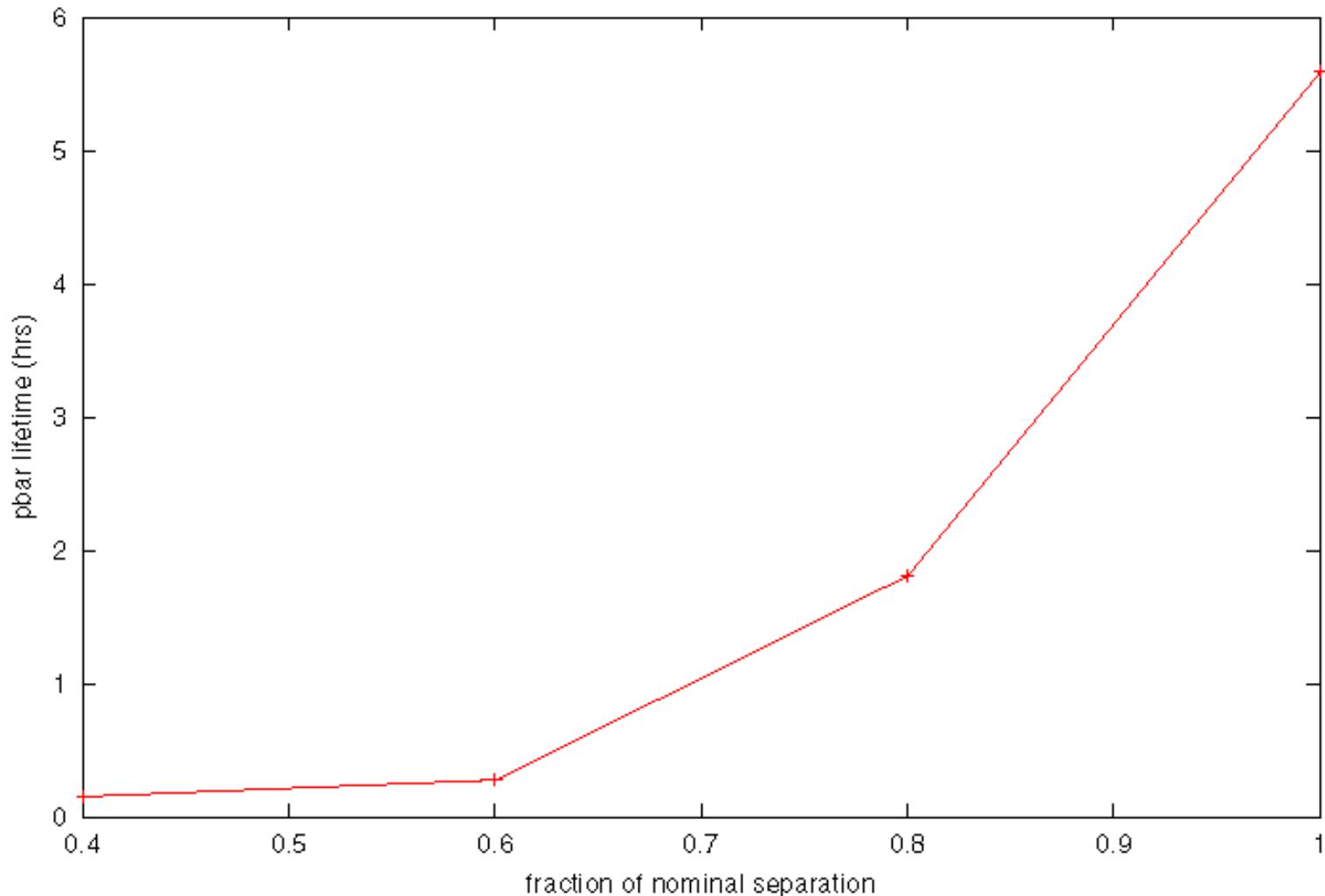
Antiproton Lifetime vs. Antiproton Emittance



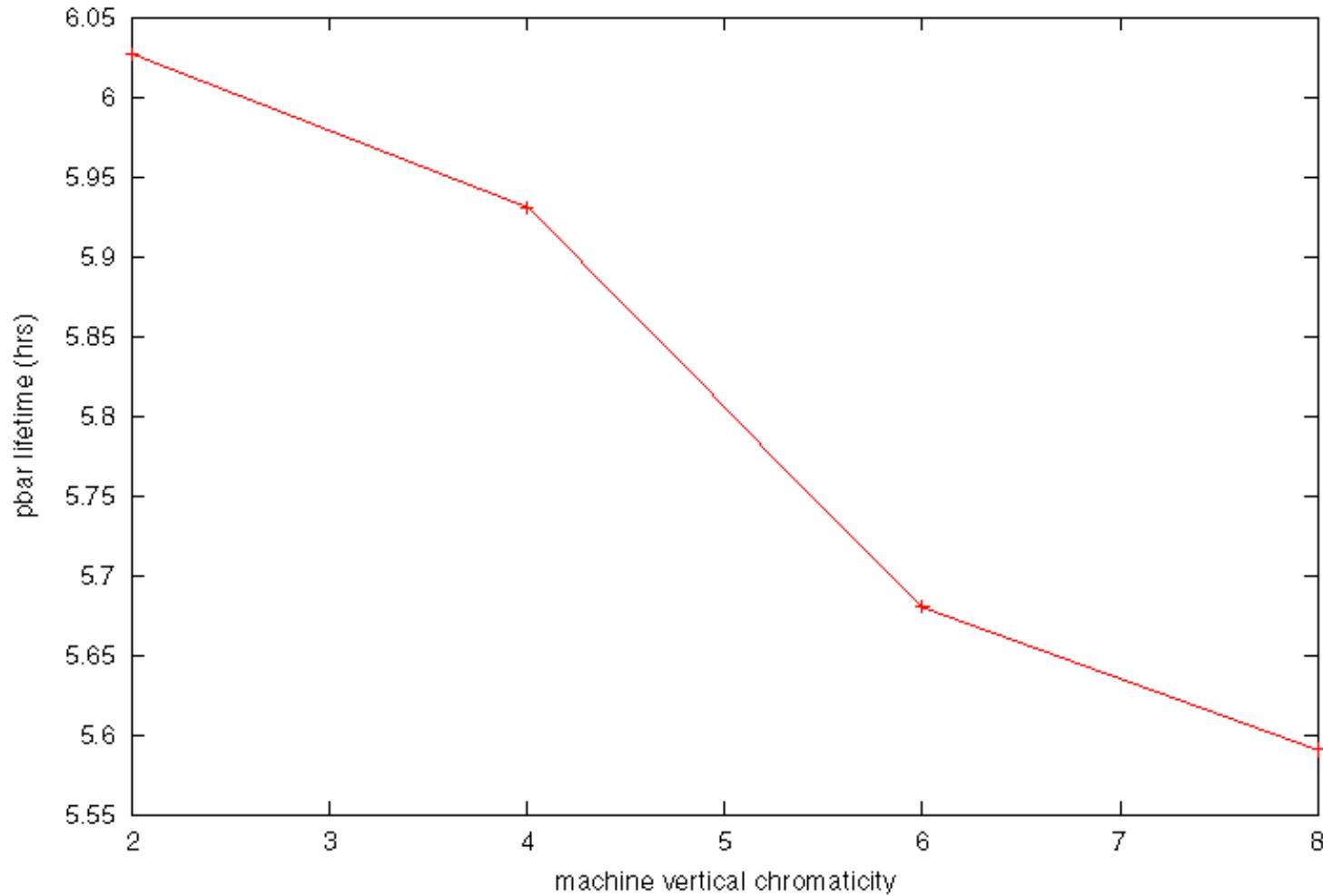
Proton – Antiproton Separation at 72 Collision Locations



Antiproton Lifetime vs. Beam-Beam Sepaction



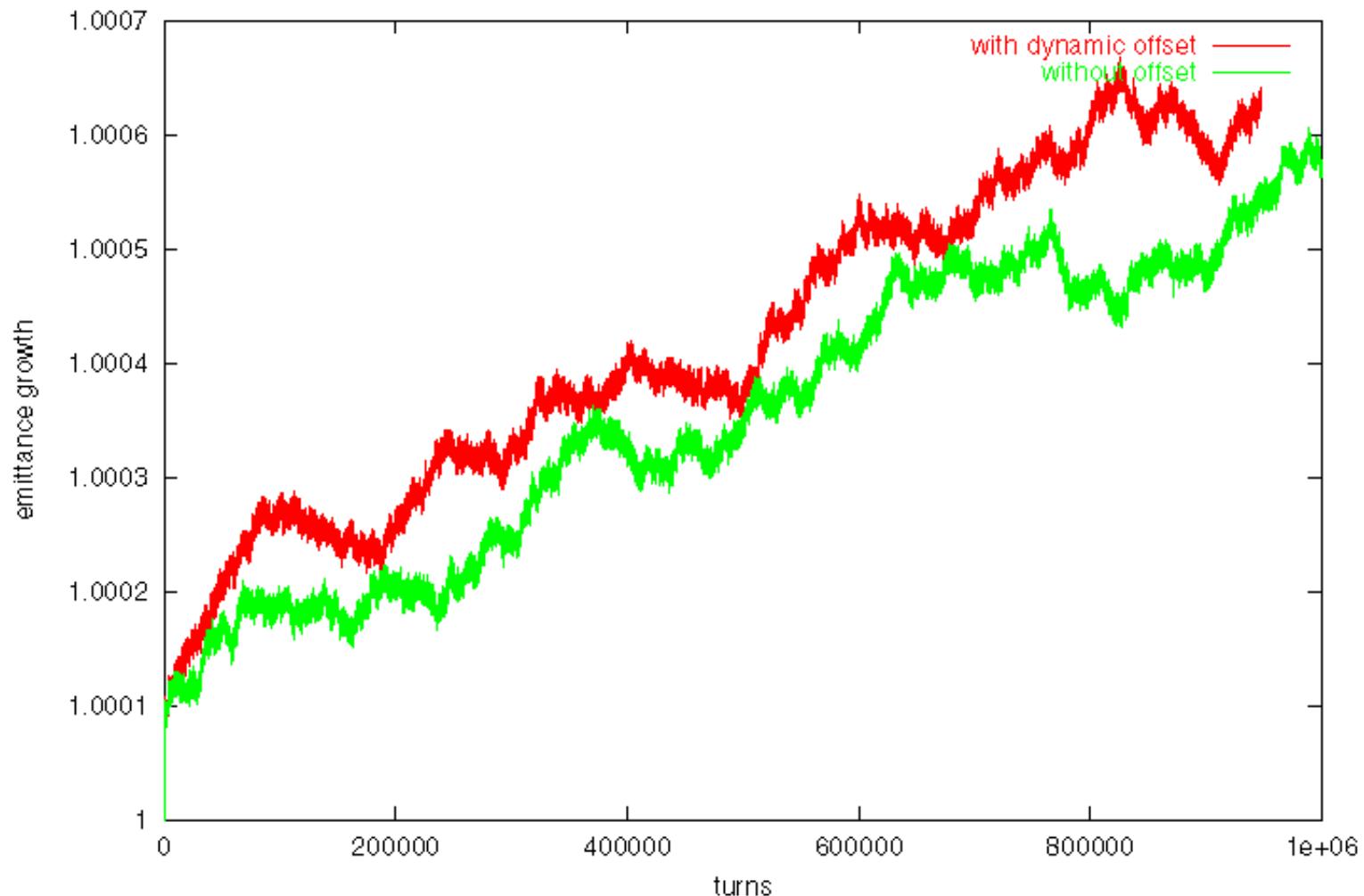
Antiproton Lifetime vs. Vertical Chromaticity



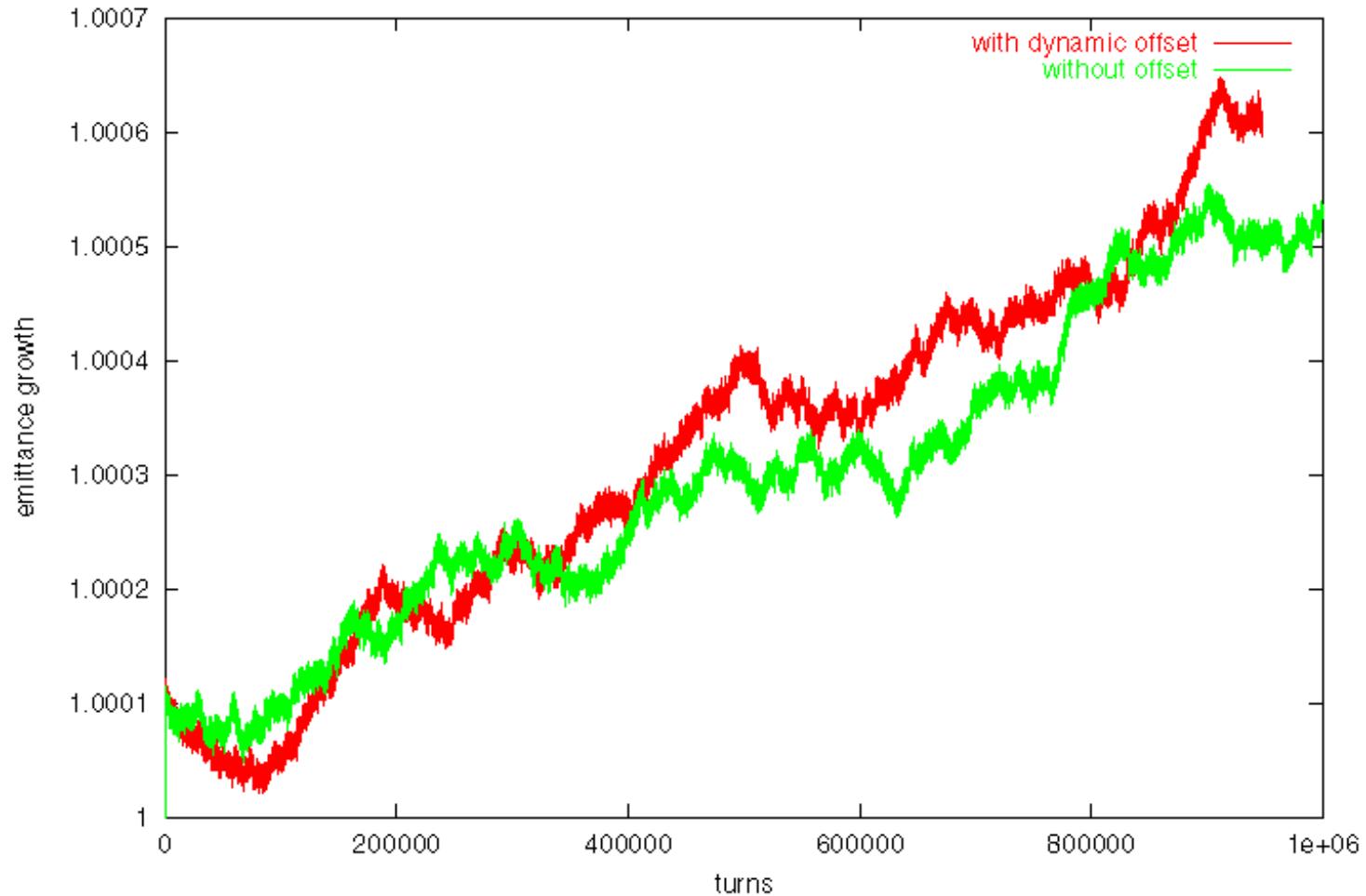
Nominal LHC Physical Parameters

Beam energy (TeV)	7
Protons per bunch	1.05e11
Beta (m)	0.5
Rms spot size (um)	15.9
Betatron tunes	(0.31,0.32)
Rms bunch length (m)	0.077
Synchrotron tune	0.0021

Averaged Emittance Growth (Beam 1)



Averaged Emittance Growth (Beam 2)



Luminosity Reduction from Finite Bunch Length Effect

